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The use of photographs to record variation in bruising response in humans

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ABSTRACT

There is considerable value in developing tools capable of accurately and reliably determining when bruises were inflicted in humans. Previous work has focused on the visual changes observed in a bruise as the injury develops and heals. However, due to variables such as how and where on the body the bruise was inflicted, differing tissue compositions at the injured skin site between individuals and inter- and intra-observer variation; a technique sufficiently robust for use in a clinical or medicolegal setting has not yet been identified. In this study we present a series of photographs taken under controlled conditions illustrating standardised bruises induced on participants using a weight dropping mechanism. We show that variation in the appearance of bruises over time across individuals is large and, although photography may be a suitable technique for the recording of injuries, it is not sufficiently reliable for determining the age of a bruise.

1. Introduction

Signs of assault are often present on the skin of victims [1,2], with bruising being the most common symptom of physical abuse [3–16]. When suspicion of abuse arises, medical staff may be asked to provide an opinion regarding when an injury was inflicted. This judgement, performed directly as the patient is being examined, or in retrospect from photographs, can aid an investigation into whether physical abuse has occurred and whether the injuries are consistent with the account provided. In the event of multiple injuries, determining whether these could have been inflicted on separate occasions would also be of value [3,13,17–25].

It is now understood that the evolution of colours present at the site of bruising reflects the different stages of haemoglobin (Hb) breakdown. Hb and variations in its appearance (red/blue/purple) will present depending on its oxidative state and depth within the skin [26]. Hb is converted into biliverdin (a green pigment), carbon monoxide and an iron atom. The iron atom binds with ferritin to produce haemosiderin, a pigment with a golden/ochre hue. Biliverdin has a short lifespan and is rapidly metabolised to bilirubin, the yellow pigment which is commonly associated with older bruises [26].

The possibility of accurately and reproducibly determining the age of bruises *in vivo* or by colour comparison aided by photography has been investigated [19,23]. However, the exact sequence, timing and duration of each colour are highly variable and no general consensus exists regarding when each colour is seen on the skin and the time it remains visible [23,27,28]. Furthermore, evidence-based guidelines required for use in a clinical or medicolegal setting are currently lacking. Extreme caution has therefore been urged when providing an opinion on the age of an injury using these methods [17,23,27,28].

Photography studies noted that bruises of identical age and aetiology present on the same individual did not necessarily display the same colours or undergo the same changes at the same rate [19,23]. Other studies have estimated the age of bruises through direct clinical observation allowing the consideration of additional physical factors, such as swelling and tenderness in the skin. This also removed any colour distortion created when photographing the injury [22]. Bariciak et al. reported a lack of accuracy amongst observers in estimating the age of the bruises, with age estimates being correct in less than 50% of the cases [22].

Studies on the accuracy of estimates between observers found extremely large intra- and inter-observer variation in the colours perceived in a bruise. This was true both for the direct examination of bruises and observation of photographic records of the injuries [21,29]. In additions, this was true of observers with different

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levels of training and experience in both clinical and forensic settings [22,25].

In response to the limited success in correctly determining the age of bruises through direct observation and photography, more sensitive techniques, such as colorimetry and spectroscopy, were investigated.

Colorimetry is a quantitative technique that classifies colour in a ratio of red, blue and green components [30]. In theory, this technique could avoid the variation introduced by human colour interpretation [31]. However, the background colour of the skin was found to be a confounding variable when using this technique [30,31]. Interpretation is also limited due to the use of only three colour values [32].

Spectrophotometry describes colours by generating spectra throughout the visible spectrum. Bohnert et al. found that injuries close to the surface of post-mortem skin appeared red whereas deeper bruises were prevalently blue in colour [31,33]. This suggested that the age of the bruise was not the only factor affecting colours perceived on the skin. Hughes et al. used varying levels of Hb and bilirubin to differentiate between recent and older bruises on living individuals [29]. Although multiple scans of the same bruise were highly reproducible, comparisons between different bruises were difficult [29,34].

Despite the increased sensitivity of these techniques, they are still limited by factors such as skin tone [29,30,33]. It is possible for a background spectra of the skin to be created when measuring the same bruise on multiple occasions, however this becomes impossible when analysing bruises present on different sites of the body, within one person and across different individuals [34].

Age [19], sex [19], diseases [17,19] and drugs, such as steroids, can affect how an individual bleeds and/or their ability to form clots [17,19] and therefore the appearance or colour of a bruise. Stress has also been associated with prolonged wound healing [35]. The anatomical location [17] and tissue composition at the site of bruising will also affect the resulting injury. The thickness of the skin varies from 1.5 to 4.0 mm depending on the functional requirements of different body parts [36]. As a result, some areas of the body will bruise more easily than others [8,37]. The severity of the injury will have an effect on the rate of healing [19,22] with small bruises having shorter healing times compared to larger injuries [38]. The force employed to injure the skin, with increasing mass and velocity leading to an increase in the area and depth of damaged tissue, has an effect on the healing response [23].

Determining the age of a bruise from direct observation or an image depends on a number of biological factors including variation in the response of individuals to injury and the ability of different individuals to perceive colours in the same way. When using techniques such as colorimetry and spectroscopy, there is a need for a record of unbruised skin tone at the site of bruising. Due to these limitations, determining the age of a bruise through observation of the injury *in vivo*, or in retrospect using photographs is inherently subjective and can be an inexact science.

In this paper, we illustrate a time series set of standardised bruises on a group of volunteers photographed under controlled conditions. Unlike other studies where results of the bruises and the variation across different bruises are not shown we have illustrated and described the evolution of bruising over the period of a week across 12 participants. These results demonstrate the visual variability in bruising response across different individuals and clearly illustrate that, under highly standardised conditions, photography is robust enough to produce visual records of bruises. However, because of the inherent variability in participant response to injury and differing examiner interpretations of images, it is not sufficient for use as a tool in determining when a bruise was induced.

2. Materials and methods

2.1. Participants

Results presented in this study were collected from 12 female participants, ranging in age from 23 to 40, with a mean age of 26 years. All of the participants were non-smokers and casual drinkers. None were pregnant and none suffered from medical conditions or had a family history of blood or clotting disorders. All of the individuals were New Zealanders of European descent except for one participant who was a New Zealander of Indian descent.

This study was approved by the University of Auckland Human Participant Ethics Committee (Reference Number 6554). Written informed consent was obtained from all participants.

2.2. Bruise site and bruise induction

To simulate blunt force injury, a 455 g (16 oz) round-ended lead weight, with a semi-spherical impact interface of 1.77 cm^2, was dropped down a fixed vertical 1-m polyvinyl chloride tube onto the participant's left bicep, which was resting on a solid surface. The pressure applied to the skin as a result of the weight drop was 0.241 kN. This was determined by investigating past bruising experiments [39,40].

This bruising technique allows for standardised bruises to be created on different individuals while controlling a number of variables during the bruising event, including the shape of the weight and the force applied to produce the injury, the location of the injury, as well as the time at which the injury was induced. In this instance all participants were bruised within a 1.5 h window.

2.3. Photography

Photographs were taken on days 3, 5 and 7 following the bruising event on day 0. No photographs of the skin were taken prior to the bruises being inflicted or in the days immediately following the infliction of the bruises. The authors chose to analyse later days to underline the variation in bruising response present across different individuals. This also allowed for the investigation of changes occurring in the bruises to be documented over a longer period of time. Photographs of bruises were taken under standardised conditions using a Nikon D90 digital SLR and Micro AF-S DX lens using the following settings: exposure time: 1/125th seconds; ISO speed: ISO-200; aperture: f/16; focal length: 40 mm. The camera was mounted on a Kaiser copy stand and tethered to a PC computer. Participants were asked to rest their arm on the baseboard of the copy stand. Identical setups and settings were used across all participants and across the three days the bruises were photographed. A Grey scale QPcard (QPC101, QPcard AB, Helsingborg, Sweden) was placed on the baseboard of the copy stand next to the participants' arm in all photographs and used as a colour and scale reference.

The lighting was provided by two Multiblitx Profilite 400 strobe units with softboxes attachments to deliver a consistent volume and wavelength of light resulting in soft and even illumination of the skin.

The images were captured as RAW files.

2.4. Scoring of bruises

A high degree of variation in bruising response was observed across the group of individuals tested (Fig. 1). Some participants barely displayed any bruising, while others developed substantial bruising over large areas of skin. One participant did not bruise at all. An arbitrary scoring system was created to categorise the bruises (Table 1). Five independent observers were given the set of three photographs for each participant and asked to score the photograph for each time point individually.

3. Results and discussion

Each image was scored for bruising intensity, and examined for bruise evolution as part of the set of three images for each participant, by five independent observers using the scale described in Table 1. A summary of the scores is in Table 2. Observers were presented with the set of three photographs for each bruised participant, the scoring scale (Table 1) and asked to score each bruise. Sets of photographs from different participants were scored independently to avoid any influence from photographs taken from different participants. In cases of disagreement between observers, the majority score was chosen. For more information on the range of scores between the different observers, refer to Appendix A.

Despite feeling pain at the site where the weight had been dropped, individual D scored zero as no discernible bruise became visible across the seven days the experiment was carried out. On photographs taken on day 3, participants A, G and L exhibited

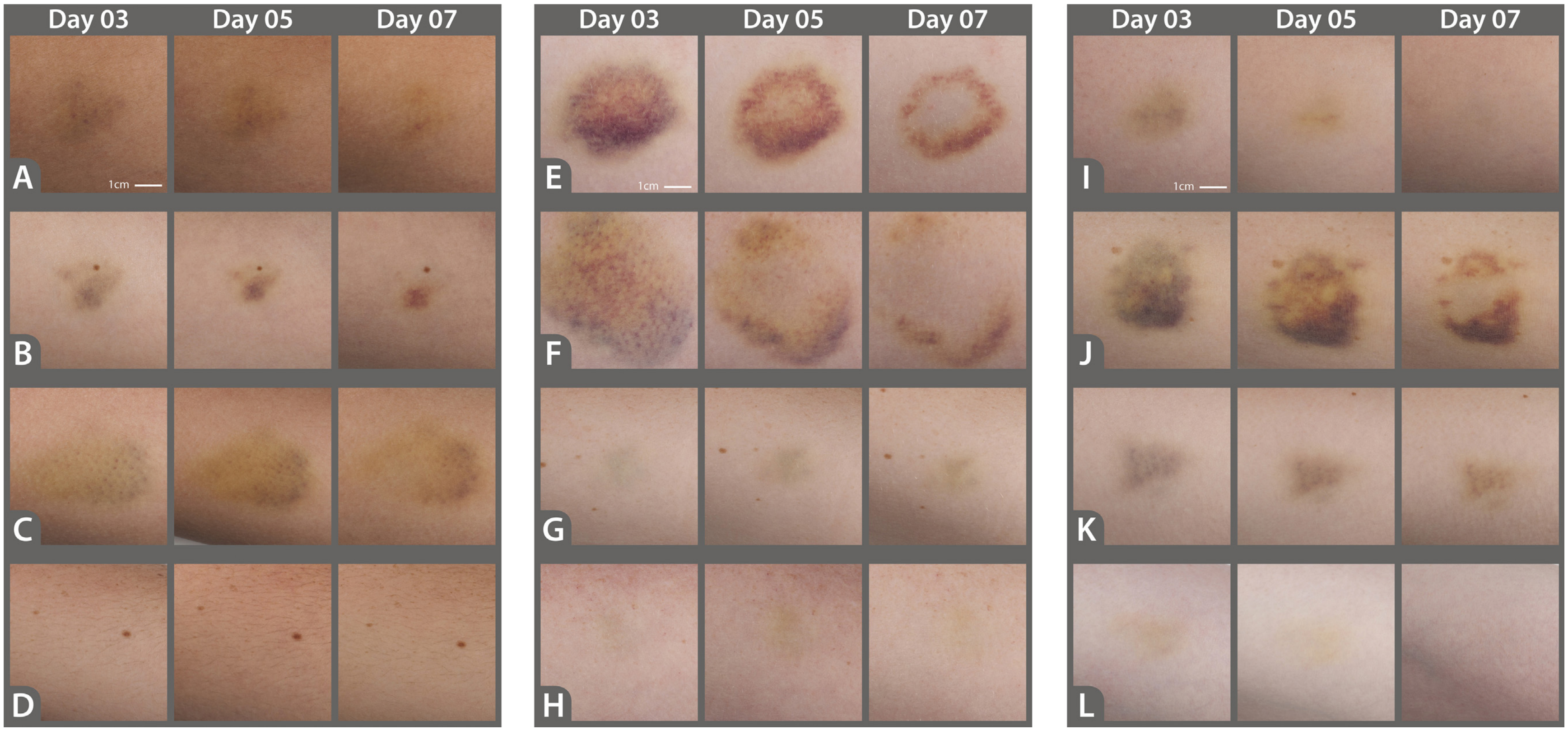

Fig. 1. Variation in human bruises. Bruises were induced using a weight drop mechanism on day 0. All participants were bruised on the same day. All participants were photographed on days 3, 5 and 7 post-bruising. All photographs were scaled to the same size as those indicated.

Table 1
Bruise scoring system. A system was created to score the photographs of the bruises. The scores indicate the degree and intensity of colouration, appearance and relative size of the injuries. Scores 2–5 also included whether an evolution in the appearance of the bruise could be noted when a photograph was compared to others within the same set for one participant.

	Scoring system
0	No discernible bruise
1	Faint bruising – some discoloration of the skin, one visible colour, small size with no clear edges
2	Light bruising – change in appearance over time, mainly one visible colour, small bruises with no clear edges
3	Medium bruising – evolution of colours over time, multiple colours although faint and difficult to annotate, medium damage size with clearer outlines
4	Heavy bruising – clear evolution of colours over time, multiple colours and easily described, large bruise area with clear edges, no bruising at site of impact at later stages
5	Acute bruising – clear evolution of colours over time, multiple colours, large bruise area with clearly delineated boundaries, no bruising at the site of impact at later stages with only peripheral bruising remaining

bruises that were given a majority score of one. These were bruises whose appearance was faint. The shape of the injuries could not be clearly delineated and no evolution in colour was seen over time. A score of two was allocated to participants C, I and K on day 3 indicating slightly larger bruises whose outlines were clearer and where changes in the appearance could be seen when examining the subsequent photographs for the same participant. Participant B was given a score of three on day 3 as their bruise was again larger in size compared to those previously described. Although it was difficult to delineate the contour of the injury; it was possible to visualise different colours and an evolution in colour over time, despite the individual colours remaining faint and difficult to describe. Injuries photographed from participants E and F were scored four on day 3. These were large bruises whose boundaries were more clearly defined than in previous scores and whose colours and evolution over time were more easily described. Finally participant J was given a score of five on day 3. Although not the largest in size, this bruise displayed the most intense colours. The boundaries of the injury were clearly delineated and different colours could be described as well as their evolution over time. The bruises observed for participants E, F and J, who scored four or five, also displayed a disappearance of colour at the initial site of bruising in the later days with only peripheral bruising remaining.

The ring-shaped configuration seen in later stages of bruising is not the result of the bruise being induced with a ring-shaped object. The force of the impact with the semi-spherical weight would have caused the blood present in the capillaries at the site of impact to be pushed towards the edge of the impact site. The movement of blood towards the margins of the impact site would have caused the tissues along the edge of the impact site to deform and capillaries to rupture [8]. This would lead to more damage and extravasated blood being present at the periphery of the injury. The chromophores present in the centre of the site of impact would be removed before those present at the edges of the injury resulting in an area of discoloration surrounded by a ring of peripheral bruising.

Participants F and J were the oldest to take part in this study (36 and 40 years old, respectively) and they displayed the highest scoring bruises (four and five, respectively). However, participants H and I (one and two stage bruises, respectively), were older than participant E, who also displayed four and five stage bruises. As previously shown [19], age does have an effect on bruising response, however the high scores observed in a considerably younger participant (E) indicate that the underlying factors responsible for bruising are much more complex.

The large amount of variation observed between these highly controlled bruises illustrates the limitations in using visual techniques to determine the age of a bruise. These images of bruises, recorded in a professional photography studio, represent a "best case scenario" for recording the injuries and might not represent the level of equipment and setup available at routine medical examinations.

The results from our study show that the formation of a bruise, including the time it takes for the injury to appear, varies between individuals. Other factors that are likely to contribute to variation are where on the body the injury was sustained and the mechanisms of bruising. Despite this, we have shown that even when controlling a large number of these variables, *i.e.* gender, the technique and force employed to create the bruises, the anatomical location where the bruises were induced, medication and disease, a large degree of variation can still be seen in the bruising response across individuals.

With such a large number of factors influencing the development and healing pattern of a bruise, it is not surprising that the search for an accurate and reproducible technique capable of determining the age a bruise has proved difficult. Some of these factors can be taken into account if the injury is being investigated *in vivo*, however this information may not be readily available, and may not have been recorded at the time the patient was examined [23]. Despite this, photographs allow for a visual record of injuries to be created and these can then be used for evidential purposes to show the extent and severity of the injuries inflicted on a victim. However, as previously described and as is illustrated in this paper, photography is not sufficiently robust to determine when an injury was inflicted.

4. Conclusions

Despite a body of work focusing on developing a tool capable of accurately and reliably estimating when a bruise was induced in living individuals, the techniques investigated to date mainly rely on the visual colour changes taking place on the surface of the skin as the injury heals. Limitations arise due to individual differences in bruising and healing response, the anatomy at the site of damage, the nature of the injury itself, and observer variation.

The absence of bruising in participant D reminds us that lack of visual evidence is not proof that a potential victim was not physically abused. Conversely, a number of medical conditions, such as Mongolian spots, Henoch-Schönlein purpura, or individuals with platelet function abnormalities may display characteristic symptoms that could be confused with bruises, resulting in misdiagnosis [41,42]. It is important to note that the presence of these conditions does not exclude the possibility of physical abuse either.

Table 2
Bruise scoring. Compilation of scores obtained from 5 independent observers. The observers were presented with the sets of images for each participant and the scoring scale and asked to provide their opinion of their score of the bruise for each of the images. Injuries were photographed on days 3, 5 and 7 after the bruising event which was called day 0. Participants were labelled A–L.

Photo	Day 3	Day 5	Day 7
A	1	1	1
B	3	3	3
C	2	3	2
D	0	0	0
E	4	4	5
F	4	3	4
G	1	1	1
H	0	1	1
I	2	2	0
J	5	4	5
K	2	1	1
L	1	1	0

The standardised photographic setup employed in this study is strong and reliable. Consistency in the conditions used for recording images of bruises is paramount for use in suspected physical abuse cases. However even under stringent conditions, photography should not be used to provide an opinion of when an injury was inflicted, as much of the biological variation is not accounted for when constructing such an opinion from photographs and this could lead to misdiagnosis.

Alternative methods, such as bio-molecular techniques should be investigated to explore the mechanism of bruising and changes that occur at the molecular level as the bruise heals. Investigations combining different approaches could provide more robust mechanisms required for the accurate determination of when a bruise was inflicted in living individuals.

Appendix A

Scoring of bruise intensity and evolution by independent observers. Five independent observers (I–V) were provided with sets of photographs taken from 12 participants (A–L) on days 3, 5 and 7 as well as a scoring scale. Observers were asked to score each photograph independently in order for the intensity of the bruises to be assessed. In addition, the sets of three photographs from each participant were also evaluated for bruise evolution over time.

Photo set	Day 3						Day 5						Day 7					
	Observer I	Observer II	Observer III	Observer IV	Observer V	Max score	Observer I	Observer II	Observer III	Observer IV	Observer V	Max score	Observer I	Observer II	Observer III	Observer IV	Observer V	Max score
A	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1
B	3	1	3	3	2	3	3	1	3	3	2	3	3	1	3	3	2	3
C	2	1	3	2	2	2	3	2	3	3	3	3	3	2	3	2	2	2
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	5	4	4	4	5	4	4	4	4	5	4	4	3	5	4	5	5	5
F	4	2	4	4	5	4	3	3	4	5	3	3	2	4	4	5	4	4
G	1	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1	1	1
H	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
I	2	1	2	2	1	2	2	2	2	1	1	2	1	0	2	0	0	0
J	5	4	5	4	5	5	4	4	5	4	5	4	4	5	5	5	4	5
K	2	1	2	2	2	2	3	1	2	1	1	1	3	1	2	1	1	1
L	1	1	0	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0

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